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(54) Title: OPTIMIZING CLEVER ANTENNA BY BEAM TILTING

(57) Abstract: A method of adjusting an antenna beam pattern of an antenna array arrangement for a wireless communication network that combines the application of a smart antenna and a clever antenna is provided. The method dynamically controls the smart antenna to adjust the beam pattern to simultaneously compensate for inter-sector interference generated by the side lobes of the beam pattern and to correct the inter-sector interference created by the over extension of the elongated main lobe of the beam pattern. In order to reduce the inter-sector interference of the side lobes, the gain of the antenna is increased to elongate the main lobe. To offset the over extension of the main lobe, the smart antenna is adjusted to balance the soft handoff boundaries in response to the traffic load detected, and the soft handoff boundaries are stabilize to match the time constants of the soft handoff parameters.

OPTIMIZING CLEVER ANTENNA BY BEAM TILTING

BACKGROUND OF THE INVENTION

1. **Reservation of Copyright.**

2. **Related Application Data**

The present application claims priority to the U.S. Application No. 09/638,906, entitled "Method and Apparatus for Classifying Wireless Nodes Within Cellular Communications Networks", filed on August 15, 2000, in the names of Shmuel Miller and Joseph Shapira. The content of the aforementioned application is hereby expressly incorporated herein by reference in its entirety.

3. **Field of the Invention.**

The present invention, generally, relates to wireless communications and in particular to base station technologies capable of dynamically controlling radiated beam patterns.

4. **Description of Background Information.**

Today's cellular communication systems are subjected to ever-increasing user demands. Current subscribers are demanding more services and better quality while system capacities are being pushed to their limits. The challenge, therefore, is to provide feasible and practical alternatives that increase system capacity while achieving better grades of service.

Typically, for each geographic cell, cellular communication systems employ a base station (BS) with an omni-directional antenna that provides signal coverage throughout the cell. One way to increase the communications

capacity, is to split the geographic cell into a plurality of smaller cells (i.e., cell-splitting) by deploying additional BSs within the cell, thereby increasing the number of frequencies that can be re-used by the system. This cell-splitting, however, can be both cost-prohibitive and environmentally-deterred as conventional BS equipment include antenna arrangements which are expensive and often too bulky and unaesthetic for prevailing community standards.

An alternative approach to improving system capacity and maintaining service quality is to angularly divide the geographic cells into sectors (i.e., sectorize) and deploy BS antennae that radiate highly-directive narrow beam patterns to cover designated sectors. The directive beam patterns can be narrow in both the azimuthal and elevation plane and, by virtue of their directional gain, enable mobile stations (MSs) to communicate with the BS at longer distances. In addition, system capacity increases, as the sectorized cells are not as susceptible to interference from adjacent cells.

The narrow beams used to form beam patterns for given coverage areas are optimized to improve performance of the wireless network. An ideal goal is to provide exceptional service quality (e.g., no dropped calls), enhanced capacity, low per-site costs enabled by large coverage areas, and long battery service periods for MSs. To this end, various methods for optimizing the antenna arrangement have been developed. For example, wireless systems engineers have historically employed BS design rules regarding RF propagation-based coverage in order to "balance the link." This approach involves controlling the BS antenna gains and antenna heights for transmission and reception, BS transmit power levels, and BS receive sensitivity parameters. These different parameters are selected to provide approximately equal coverage for the MS-to-BS link (i.e., reverse link) as is provided for the BS-to-MS link (i.e., the forward link).

A need still exists to further lower costs of deployment and operations and to provide better coverage/capacity at lower costs. Accordingly, steps have been taken to introduce new technologies, such as CDMA technologies, for example, which can operate in environments involving high intra-system interference and yet provide exceptionally high capacity with low transmit power levels. These new environments and technologies require even more

sophisticated network and design approaches and interference mitigation strategies.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be further understood by reference to the illustrated drawings by way of non-limiting exemplary embodiments, which use like reference numerals to represent similar elements throughout, and wherein:

FIG. 1 is a illustration of soft hand-off zones.

FIG. 2 is a high level diagram illustrating a shaped composite beam;

FIG. 3A is a high level diagram depicting an exemplary antenna arrangement;

FIGS. 3B and 3C show beam patterns;

FIG. 4 is a depiction of how an increase in the gain of the antenna elongates the beam;

FIG. 5 utilizes a free space propagation model to illustrate inter-cell interference;

FIG. 6 illustrates a conventional beam tilting method;

FIG. 7 graphically shows how beam tilting increases the capacity within a coverage area or allows a reduction in power;

FIG. 8 illustrates a conventional beam tilting method using a power reduction technique;

FIG. 9 depicts the deployment of the "smart antenna" and the "clever antenna" according to the invention

FIG. 10 illustrates the beam tilting technique according to the invention; and

FIGS. 11A and 11B demonstrates the beam tilting technique according to the invention.

DETAILED DESCRIPTION

In order to achieve efficient utilization of the radio spectrum deployed within a wireless system, an operating scheme that optimizes the capacity of the network and minimizes interference within the network is the optimum goal. Since interference has been recognized as the major limiting factor in the performance of a wireless network system, there is a constant ongoing battle for designers of wireless systems to increase the capacity while decreasing the

interference. Sources of interference may include another MS in the same cell, a call in progress in a neighboring cell, other BSs operating in the same frequency band, or any noncellular system which inadvertently leaks energy into the cellular frequency band.

Certain network optimization features are described and discussed in detail in copending patent application Serial No. 09/357,844, entitled "ACTIVE ANTENNA ARRAY CONFIGURATION AND CONTROL FOR CELLULAR COMMUNICATION SYSTEMS" filed on July 21, 1999, the content of which is hereby incorporated by reference in its entirety. As indicated in the referenced patent application, optimization of a wireless communication network may occur through the manipulation of various parameters and characteristics of the beam. These parameters and characteristics may include reverse link attributes, forward link attributes, soft hand-off zone balancing, coverage/capacity control of the reverse link, various diversity schemes zones to mitigate path losses, and beam shaping optimization of the forward and reverse links.

One optimization scheme focuses on Soft Handoff (SHO) zone balancing to manage traffic loads between cells. For example, an overloaded cell may be reduced, while a lightly-loaded adjacent cell may be expanded to manage some of the traffic load. When a MS approaches the boundary of one cell, the wireless network senses that the signal is becoming weak and automatically attempts to hand off the call to the antenna of the BS in the adjacent cell into which the MS is traveling. When the MS travels into a different cell while a conversation is in progress, a Mobile Switching Center (MSC) transfers the call to the corresponding BS. Thus, the handoff operation requires that the MSC identify the corresponding BS to receive the call.

Wireless networks employing IS-95 Code Division Multiple Access (CDMA) techniques provide the ability to allow the MSC to simultaneously evaluate the received signals from a single MS at several neighboring BSs as well as enabling the MSC to decide which version of the MS's signal is best at any moment in time. The ability to select between the instantaneous received signals from a variety of BSs is called a soft handoff. This soft handoff is associated with a Soft Handoff (SHO) zone. The SHO zone is the area where

the transmission of the MS within a given geographic region reaches the receivers of two or more relevant BSs with signal levels suitable for proper reception to maintain communications. SHO zones, SH1, SH2, SH3, and SH4, are exemplified in FIG. 1.

In a simple scenario of two equally loaded cells, the SHO zone is proximately located around the geographical line bisecting the intersection of two adjacent cells. The SHO zones define the geographic area where a MS decides which of the BSs of the two adjacent cells it should communicate with. The boundary of the SHO zones are determined by the BSs (based on reports from the MS) and the MSs, which measure the Ec/Io of the pilot signals generated by the BSs.

Another optimization scheme focuses on maximization of the beam radiated within the cell/sector to reach as many MSs as possible; thus, maximizing the in-cell capacity of the network. This may be achieved by relying on antennas exhibiting a shaped beam 5 in the elevation plane because elevation beam shaping supports the control of front-to-back cellular/sector coverage, as illustrated in FIG. 2. The beam patterns radiated from the BS antenna should transmit a minimum level of field strength within the coverage area of a sector or cell to assure proper communication with the MSs within the geographic area.

Two common impediments that may develop within a wireless communication network and adversely affect the optimization of the in-cell capacity are fading and inter-sector interference. Fading is the fluctuation of the received signal due to multipath propagation. Fading is caused by interference between two or more versions of the transmitted signal, which arrive at the receiver at slightly different times. The loss in signal strength due to propagation incurs large variations in cluttered, urban areas. Most notorious are the penetrations into buildings. In urban areas, fading occurs because the height of the MS antennas are well below the height of surrounding structures, so that there may be no single line-of-sight (LOS) path to the BS. The radio waves arrive from different directions with different propagation delays, so that the signal received by the MS at any point in space may consist of a large number of plane waves having randomly distributed amplitudes, planes, and angles of

arrival. These multipath components combine vectorially at the MS receiver antenna, and can cause the signal received by the MS to distort or fade. Even when a MS receiver is stationary, the received signal may fade due to movement of surrounding objects within the radio channel.

When these multipath components combine at the receiver antenna to provide a resultant signal, the resultant signal may vary widely in amplitude and phase. This variance increases the required energy to detect the received signal correctly (commonly noted as Eb/Io, energy per bit over the spectral density of the noise and interference). As a result, higher transmission power, and/or higher antenna gain into these directions, is then required to maintain these links. The BS may become power-limited.

Inter-sector interference, as mentioned, is another culprit may adversely affect the in-cell capacity. Inter-sector interference may be generated when the BS antenna 10, exemplified in FIG. 3A, projects the beam outwardly into the sector 35 in FIG. 3. The beam pattern may form a main lobe 10 as well as side lobes 15, as shown in FIGS. 3B and 3C. Unfortunately, these side lobes 15 have a tendency to bleed over into adjacent sectors 20, 25 within a cell 30, causing inter-sector interference, as depicted in FIG. 4. Thus, an attempt to optimize the in-cell capacity of may create interference between the sectors.

As such, the network may have to dynamically readjust its parameters to compensate for the inter-sector interference. The amplitude, phase and/or gain adjusting elements of the network make it possible to control the shape of the antenna beam patterns. In a CDMA scheme to reduce inter-sector interference, the in-cell capacity of the network may be increased by narrowing the sector width of the beam radiated from the BS's antenna in order to reduce the inter-sector interference generated by the side lobes 15 of the beams. Accordingly, wireless network designers have attempted to employ "smart antennas" in BSs to minimize inter-sector interference.

Features of smart antennas are described in detail in U.S. provisional Patent Application No.60/177,659, entitled "CELL AND SECTOR OPTMIZATION SYSTEM AND METHODS", filed on 60,177,659 and herein incorporated by reference. In particular, the referenced patent application discusses in detail how smart antennas may be used to optimize the cell and

sector design of a wireless network system. One objective of the "smart antenna" in CDMA is to minimize the inter-sector interference by increasing the gain of the antenna along a predetermined direction. The gain increase results in increasing the radial length of the beam main lobe while narrowing the beam width of the main lobe, as well as reducing the magnitude of the beam side lobes. By increasing the gain of the antenna, as shown in phantom in FIG. 4, the main lobe 10a of the beam is elongated in the radial direction, and the side lobes 15a are decreased in the azimuthal plane. The extension of the beam 10a in the radial directions allows the beam to extend further outwardly into the sector so that more subscribers are efficiently serviced, thus increasing a higher density of MSs. Due to the reduction in the side lobes 15a, inter-sector interference is reduced since the area of overlap between the side lobes of adjacent sectors is reduced.

Unfortunately, the elongated main lobe 10a of the beam, although extended to decrease inter-sector interference while increasing in-cell capacity, may over extend into an adjacent cell 40 to create inter-cell interference. Thus, this adjustment of the extension of the beam may adversely affect the traffic loads shared between two adjacent cells, which in turn adversely affects the SHO zone. Consequently, the network must, once again, readjust its parameters to compensate for the newly generated inter-cell interference.

Therefore, a problem exists in that there is an inherent conflict between maximizing the gain of the beam to maximize the in-cell capacity and maintaining the radial length of the beam constant to maximize the traffic load shared between cells.

To compensate for such a conflict, there are inherent features that exist within a wireless communications network which may assist in reducing inter-sector interference. Nevertheless, developers of wireless communication networks cannot rely solely on these inherent features to resolve this conflict. One such inherent feature is the concept of frequency use. Central to the cellular concept is frequency reuse, which is critically dependent upon the fact that the carrier wave power of the radiated beam decays with increasing distance. Consequently, the field strength of the beam pattern emitted out of the coverage

area is expected to diminish sharply beyond the cell boundary to help eliminate the occurrence of inter-cell interference.

FIG. 5 uses a free space propagation model to illustrate inter-cell interference. The free space propagation model in FIG. 5 predicts that the received signal strength when the transmitter and receiver have a clear, unobstructed LOS path between them. The free space model predicts that the received power decays as a function of the transmitter-receiver (T-R) separation distance raised to a power law function. A free space propagation exponent of 4 was used during experimentation and the distance was plotted on a log scale. However, in FIG. 5, the free space propagation is suppressed and illustrated as (R^2)-plot for the sake of compactness of the illustration. The asymptotic propagation is R^{-4}, while the average exponent at shorter distances is 2, and even closer. In the side lobe region, the transmission loss has an average flat level. To assure proper communication with the subscribers within the cell, the cell boundary 45 has to be set well within the asymptotic region. FIG. 5 illustrates that the transmission loss decays with distance at a rate of 20 dB/decade. The parameter controlling the break point of the transmission loss of the radiated beam is the height of the antenna.

However, as previously mentioned, the inherent features of the network by themselves are insufficient to readjust the network to offset the disturbance created when the above-discussed conflict develops within the system. A need may arise to reduce the coverage average of the transmitted beam, beyond the effects derived from the inherent features, when:

- There is an excessive interference source, and the reverse link range should be reduced;

- The forward link interferes with other cells, and the coverage area of the forward link should be reduced; and

- A microcell is designed to have a limited coverage area.

As a result, in order to maintain an optimized network, the network's parameters must be constantly monitored and adjusted accordingly to accommodate for different dynamics resulting from MSs travelling in and out of

the network. It is important to note, however, that when adjustments are made with respect to one parameter, such adjustments may adversely affect the operation of other parameters.

As such, there exists a need for improvements in employing a smart antenna systems and arrangements as well as systems for dynamically controlling antenna beam patterns in light of the above-identified issues.

A conflict may develop between maximizing the gain of the beam to increase the in-cell capacity and maintaining the radial length of the beam constant to maximize the traffic load sharing between cells and stabilize the SHO zones. In particular, the elongated main lobe 10a of the beam illustrated in FIG. 4, although extended to decrease inter-sector interference while increasing in-cell capacity, may over extend into an adjacent cell 40 to create inter-cell interference. As such, the the extension of the beam may adversely affect the traffic loads shared between two adjacent cells, which in turn adversely affects the SHO zone. Consequently, the network has to, once again, readjust its parameters to compensate for the newly generated inter-cell interference.

To combat such inter-cell interference, wireless network designers have attempted to employ "smart-antennas" in BSs to increase the in-cell capacity. The patent application entitled "CELL AND SECTOR OPTIMIZATION SYSTEM AND METHODS", discusses in detail how a smart-antennas may be used to optimize the cell and sector design of a wirelsss network system. However, a problem occurs when smart antennas are used to narrow the shape of the beam to increase in-cell capacity. As discussed-above, inter-cell interference may be created within the system which adversely affects the SHO zones.

Moreover, efforts have been undertaken to utilize beam tilting of the smart antenna to address, not only the above-mentioned problems, but also specific problems the may arise due to inter-cell interference adversely affecting the SHO zone. Beam tilting provides two major benefits—it shrinks the cell boundaries, while increasing the field of the beam radiated within the coverage area. Beam tilting increases the capacity within a coverage area or allows a reduction in power, as shown in FIG. 7. In addition, when beam tilting is used

in conjunction with diversity techniques, fading may also be reduced. Various beam-tilting related aspects of the application may invoke techniques or concepts, some of which are disclosed in the following references: J. Shapira: Microcell Engineering in CDMA Networks, IEEE Trans. Veh. Technology, Vol. 43, pp. 817-825, Nov. 1994; D. H. Kim, D.D. Lee, H.J. Kim, and K.C. Whang: Capacity Analysis of Macro/Microcellular CDMA with Power Ration Control and Tilted Antenna, IEEE Trans. Veh. Tech., Vol. 49, No. 1, pp. 34-42, Jan. 2000: and Qualcomm, Inc.: The CDMA Network Engineering Handbook, Vol. 1, chapters "Antenna Systems" and "Microcells", Nov. 1992. The content of each and every one of these references is hereby expressly incorporated by reference in their entireties.

As the demand for service within a network increases, especially in urban areas, traffic load sharing schemes are employed between a loaded cell and a lightly load cell to manage the load demands within a cellular system. The network capacity relates to maximizing the overall usage of the network, given a load distribution. This encompasses sharing load between cells and maximizing the Grade of Service (GOS) within the SHO zones. As previously discussed, the SHO zones are geographic areas surrounding the balance line where the MS transmission meets the threshold of both base transceiver station (BTS) in the adjacent cells. However, the boundary of the SHO zones is determined by the measurement of the Ec/Io of the pilots by the MS, which also serves to measure the threshold for detectability of the forward link. The forward link coverage is measured by the detectability of environment-dependent orthogonality of codes, in the presence of a small number of other interference sources, and the reverse link coverage is measured by detectability of non orthogonal random sequences in a power controlled environment. The reverse link and the forward link do not match and have to be balanced by controlling the coverage shape of the SHO zone.

Three common problems that may affect the SHO zone due to inter-cell interference within the system are:

First, the soft handoff zone boundaries, defined by measuring the pilot transmission from the BSs, have to encapsulate the zone where the MS transmission reaches both base stations with signal levels about equally proper

for detection. These two conditions are set separately, and may be violated when the load ratio between the cells, or other conditions, change. It may, therefore, necessary to employ a mechanism that moves the SHO boundaries with the changing conditions – by controlling the power transmitted for the pilots or the relevant antennas' gain, or by setting a wide SHO zone to allow for changes. However, the latter solution costs in assets and in performance, and therefore – in capacity. It increases the number of MS under the SHO; thereby it requires a larger number of modems/ processors ("channel cards") in each BS, and a higher transmission power from each BS. Moreover, the SHO is more sensitive to performance disturbances than the core of the cell during the access period, and its enlargement reduces the overall performance (Grade Of Service – GOS) and the capacity.

Second, more than two BSs may be involved in a given SHO zone, and the transmission of their pilots interferes with each other, a phenomena known as "pilot congestion", and is the cause of major deterioration of the GOS.

Third, the adaptive beam forming responds to tele-traffic requirements. These are dynamic, and will be more so for data transmission, as in the third generation of cellular system that is emerging. Such a dynamic creates a fast changing SHO (conditions for the reverse link) and SHO boundaries (pilot transmissions) that are not necessarily concerted, and certainly not between cells.

Such dynamic changes in the reverse link boundary may not be matched by respective changes in the SHO boundaries, which are dictated by the Ec/Io of the respective BS pilot signals. Consequently, the over extension of the elongated beam not only creates inter-cell interference, it may also compromises the integrity of the SHO zone. In sum, the radial length of the beam main lobe 10a may be extended to the point where it spills over into an adjacent cell 40. Such spill-over directly effects the SHO zone boundaries, which ultimately impacts traffic load sharing between cells. Thus, the of conflict between maximizing the gain of the beam to maximize in-cell capacity and maintaining the radial length of the beam constant to maximize traffic load sharing between cells still persists when the parameters of the network are adjusted using the technique of beam tilting a smart antenna.

Ideally (and theoretically), the problem identified above could be solved by dynamically controlling the "smart" antennas in all the cells in the cluster to adjust the beams to match the changing SHO boundary. However, this is an onerous task, fraught with processing difficulties, and huge signaling traffic, and limited by the time constants of SHO setting processes.

A more optimal solution may be achieved by balancing the SHO boundaries in response to the traffic load sharing balance and stabilizing them to match the time constants of the SHO commands. This balance relates to accumulated interference and can be achieved by measuring and controlling the inter-cell interference, without resorting to the detection of the signals for each user. A great deal of simplicity is achieved by taking this novel approach and avoiding the interaction with the base station core operations.

As the SHO zone boundaries are dominated by interference, they cannot be controlled by utilizing only the beam-shaping aspect of the "smart antenna". Full dynamic control of these boundaries becomes an insurmountable task and requires that the time constants of the "smart antenna" controls match that of the SHO boundary setting. A sub-optimum is set by balancing the cell boundaries to the regional load balance, and not to a specific MS need. This requires that the beam formed by the "smart antenna" be controlled to match a certain radial boundaries. This is the task of the "clever antenna". The "clever antenna" is discussed in detail in the related application entitled "CELL AND SECTOR OPTIMIZATION SYSTEM AND METHODS".

Implementation of the "Smart" and "Clever" antenna for CDMA is schematically described in FIG. 9. As described schematically in FIG. 9, beam 50 is the beam under consideration, beam 55 is an adjacent beam serving another MS, and beam 60 is a beam in BTS #2, serving an MS in that cell, that collides with beam 50.

The interference to the pilot transmitted with beam 11 consists of three terms:

$$I_0/E_c \;\alpha\; \beta^*P_{B2}/P_{B1}{}^*G_{20}/G1_1{}^*((2R-r)/r)^{\wedge}{-4} + OP/\beta + OP/\beta\; {}^*G_{10}(\phi)/G_{11}(\phi) \quad (1)$$

where:

β is the fraction of the BTS transmit power allocated to the pilot

$P_{B1,2}$ is the transmit power of BTS # 1,2, respectively

$G_{11,20,10}$ is the gain of the respective beam

R is the nominal radius of the Cell

r is the radial variable

OF is the Orthogonality Factor

ϕ is the azimuthal angle

The first term, $P_{B2}/P_{B1}*G_{20}/G1_1$, relates to the interference from the adjacent cell and depends on the radial variable. It sets the radial dependence of T_{AD}. The second term, ((2R-r)/r)^-4 +OF/β + OF/β, is the multipath interference within the beam 11. The third term, $G_{10}(\phi)/G_{11}(\phi)$, is the interference from other beams, and represents the angular rejection of the interference by the "smart antenna".

In order for the SHO zones to be stable, the first term has to be stabilized and not dependent on the smart antenna fast dynamics. This is achieved by maintaining the ratio of equation (2) constant.

$$P_{B2}/P_{B1}*G_{20}/G1_1 \qquad (2)$$

As such, the clever antenna endeavors to maintain the SHO zones by maintaining the ration of equation (2) constant.

By adapting the concept of beam titling to the clever antenna, the network system is able to simultaneously compensate for the inter-sector interference generated by the side lobes and to correct the inter-sector interference created by the over extension of the elongated main lobe. As discussed previously, in order to reduce the inter-sector interference of the side lobes, the gain of the antenna is increased to elongate the main lobe. However, the requirement stated in Eq. (2) conflicts with maximizing the gain and thus maximizing the capacity within the cell, and thus limits the effectiveness of the smart antenna. This conflict between the beam width (gain) and the radial extension of the beam can be resolved by beam tilting of the clever antenna, which serves to separate the radial and azimuthal variables. The beam titling control of the clever antenna follows a sub-optimizing process, based on the regional loads, rather than adapting to each MS beam setting. This novel

approach yields the benefit of simplicity for designing both the antenna hardware and antenna controls.

As an illustrative example, a 4-column antenna array can generate a beam of 30° (azimuthal gain of 6 dB in a 120° sector), and an 8-column antenna array are capable of generating a beam of 15° (9 dB gain). This is compensated by a beam tilt of one beam width.

Beam tilting serves to separate the radial and azimuthal variables due to the fact that an antenna is an angular filter. It distributes a given power into a certain pattern, and thus creates high intensity (gain) in certain direction while suppressing others. The narrower the beam the antenna forms, the higher the density of radiation in that direction. This radiation density translates into the distance where the signal can be detected. When the beam is down-tilted, the gain toward the horizon is reduced, while preserving essentially the beam width, as illustrated in FIG. 10. This is the mechanism by which the bandwidth and the radial extension can be controlled separately.

By tilting the beam downwardly, as illustrated in FIGS. 11A and 11B, beam tilting shrinks the cell boundaries, as explained above, and provides for capacity increase. By doing so, the gain for lower angles (looking into the cell coverage area) is higher, thus providing more power density to cover uneven loss, as in building penetration, while suppressing the gain toward other cells.

In accordance with the invention, the cellular network is optimized by dividing the network into a plurality of adjacent geographic cells. A group of radio channels, used by the BS having an antenna that generates a beam within each geographic cell, is allocated within the system. Then, the geographic cells are divided angularly into sectors. The BS antenna arrangement is deployed to radiate the beam to form a beam pattern covering the sectors of the geographic cells. Each beam pattern may include a main lobe and a side lobe. A soft handoff zone is determined such that a MS travelling from one cell to an adjacent cell can decide which base station of the two adjacent cells the mobile station should communicate with. The system determines the load information of the network based on the number of mobile stations travelling within the network. The gain of the antenna is adjusted to reduce any overlapping interference occurring between the beam patterns pertaining to adjacent sectors.

Finally, the tilt of the beam pattern is adjusted to decrease any overlapping interference occurring between the beam pattern of adjacent cells such that the beam patterns fall within the soft handoff zone while maintaining the width of the beam.

Although attempts have been made to employ conventional mechanical and electrical beam tilting schemes to limit or reduce the coverage area in order to mitigate the effects of inter-cell interference, as depicted in FIG. 6, these conventional techniques suffer from several deficiencies. As demonstrated in FIG. 8, some conventional beam titling processes have attempted to reduce the cell coverage area by reducing the power of the BS antenna while tilting the beam. However, this method does not change the cell change boundaries (the distance from the break point), but instead reduces the field of the beam transmitted within the cell. Thus, the grade-of-service experienced by the MS is reduced.

Another conventional method employs mechanical beam titling by mounting an antenna to a supporting structure, (i.e., a building) and physically tilting the antenna to adjust the beam. A shortcoming of mechanical beam tilting is that it does not change the antenna pattern, within its own coordinate reference. However, it changes the footprint of the beam on the ground, as the footprint is a cut in the radiation envelope by a plane that is titled upwardly. There is not a resulting change at 90° off the boresight, while the gain at the boresight projection is reduced. The main beam thus widens, and takes the form of a "beam" when the tilt approaches a full beamwidth. The backlobe is suppressed, as it shoots upward.

On the other hand, electrical tilting involves a change in the phasing of the vertical aperture, so that the beam pattern tilts around the vertical axis of the antenna. Electrical tilting deteriorates the pattern of the beam because phasing the aperture may have adverse effects on the vertical plane of the antenna radiation envelope ("vertical pattern") – increased side lobe level, and mainly – grating lobes rising at large vertical angles. These may be large enough to reduce the antenna gain. Parameters relating to these effects are:

- The spacing between the excited antenna elements. Spacing greater than .8 wavelength may generate substantial grating lobes even with one beamwidth tilt.

- The granularity of the phasing (sub-array phasing). Whenever sub-arrays maintain their broadside pattern, and phasing is applied between them, grating lobes appear deep within the visible space. Their detrimental effect in the cellular application is when they suppress the gain in the main beam.

While the invention has been described by way of example embodiments, it is understood that the words which have been used herein are words of description, rather than words of limitation. Changes may be made, within the purview of the appended claims without departing from the scope and the spirit of the invention in its broader aspects. Although the invention has been described herein with reference to particular structures, materials, and embodiments, it is understood that the invention is not limited to the particulars disclosed.

WHAT IS CLAIMED:

1. A method of adjusting an antenna beam pattern of an antenna array arrangement for a wireless communication network, comprising:

dividing the network into a plurality of adjacent geographic cells;

allocating a group of radio channels to be used by a base station having an antenna that generates a beam within each geographic cell;

determining the load information of the network based on the number of mobile stations;

sectorizing the geographic cell by angularly dividing the geographic cell into sectors;

deploying a base station antenna arrangement to radiate beam patterns covering predetermined sectors of the geographic cells, each of said beam patterns containing a main lobe and side lobes;

defining a geographic area as a soft hand off zone such that a mobile station travelling from one cell to an adjacent cell can decide which base station of the two adjacent cells with which the mobile should communicate;

adjusting the gain of the antenna to reduce any overlapping interference occurring between beam patterns pertaining to adjacent sectors; and

adjusting the tilt of the beam pattern of the antenna to decrease any overlapping interference occurring between the beam pattern of adjacent cells such that the beam patterns fall within the soft handoff zone while maintaining the width of the beam.

2. A method of adjusting an antenna beam pattern of an antenna array arrangement for a wireless communication network, comprising:

defining a geographic area as a soft hand off zone such that a mobile station travelling from one cell to an adjacent cell can decide which base station of the two adjacent cells the mobile station should communicate with;

determining the time constants of the soft hand off zone;

determining the load information of the soft hand off zone based on the number of mobile stations;

providing a smart antenna;

employing the smart antenna to balance the boundaries of the soft hand off zone in response to the traffic load and to stabilize the boundaries of the soft hand off zone to match the time constants of the soft hand off zones.

3. A method of adjusting an antenna beam pattern of an antenna array arrangement for a wireless communication network, according to claim 2, further comprising:

detecting a forward link of the network and a reverse link of the network; and

wherein the soft hand off zone is balanced by adjusting the forward link and the reverse link.

4. A method of adjusting an antenna beam pattern of an antenna array arrangement for a wireless communication network, according to claim 3, wherein the reverse link is adjusted to match the forward link.

5. A method of adjusting an antenna beam pattern of an antenna array arrangement for a wireless communication network, according to claim 2:

dividing the network into a plurality of adjacent geographic cells;

allocating a group of radio channels to be used by a base station having an antenna that generates a beam within each geographic cell;

determining the transmit power of the base station;

determining the gain of the beam transmitted within the networks; and

employing the smart antenna to maintain the ratio of the $P_{B2}/P_{B1} * G_{20}/G_{11}$, wherein P_{B2} and P_{B1} are the transmit power of adjacent cells, respectively and G_{20} and G_{11} are the gain of the respective beams.

6. A method of adjusting an antenna beam pattern of an antenna array arrangement for a wireless communication network, comprising:

detecting the interference of a pilot signal transmitted within the network such that the following representation is satisfied:

$$I_0/E_c \;\alpha\; \beta * P_{B2}/P_{B1} * G_{20}/G1_1 * ((2R-r)/r)\verb|^|{-4} + OF/\beta + OF/\beta * G_{10}(\phi)/G_{11}(\phi) \qquad (1)$$

wherein :

β is the fraction of the BTS transmit power allocated to the pilot

$P_{B1,2}$ is the transmit power of BTS # 1,2, respectively

$G_{11,20,10}$ is the gain of the respective beam

R is the nominal radius of the Cell

r is the radial variable

OF is the Orthogonality Factor

ϕ is the azimuthal angle

adjusting the tilt of the beam of a smart antenna to separate the radial and azimuthal variables in the representation.

7. A method of adjusting an antenna beam pattern of an antenna array arrangement for a wireless communication network, comprising:

dividing the network into a plurality of adjacent geographic cells;

allocating a group of radio channels to be used by a base station having an antenna that generates a beam within each geographic cell;

determining the load information of the network based on the number of mobile stations;

sectorizing the geographic cell by angularly dividing the geographic cell into sectors;

deploying the antenna to radiate the beam pattern to cover the sectors, wherein each beam pattern generates a main lobe and side lobes configuration;

defining a geographic area as a soft hand off zone so that a mobile station (subscriber) travelling from one adjacent cell to another adjacent cell can decide which base station of the two adjacent cells the mobile station should communicate with;

increasing the gain of the antenna to elongate the distance of the main lobe of at least one of the sector and to reduce any overlapping interference occurring between the side lobes of adjacent sectors;

adjusting the beam pattern downwardly and simultaneously increasing the gain of the antenna to decrease the elongated main lobe to fall within the soft handoff zone while maintaining the width of the beam.

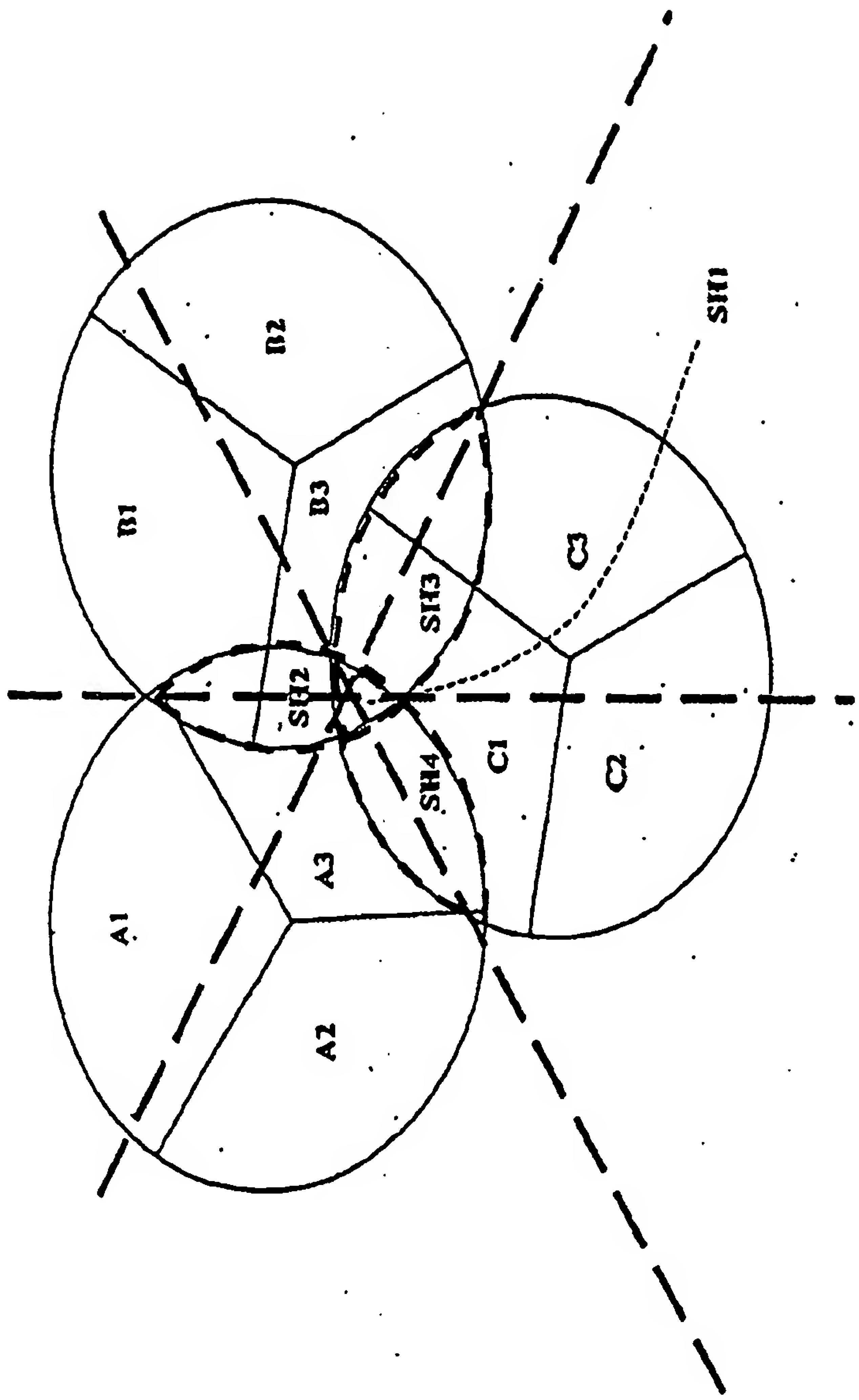

FIG. 1

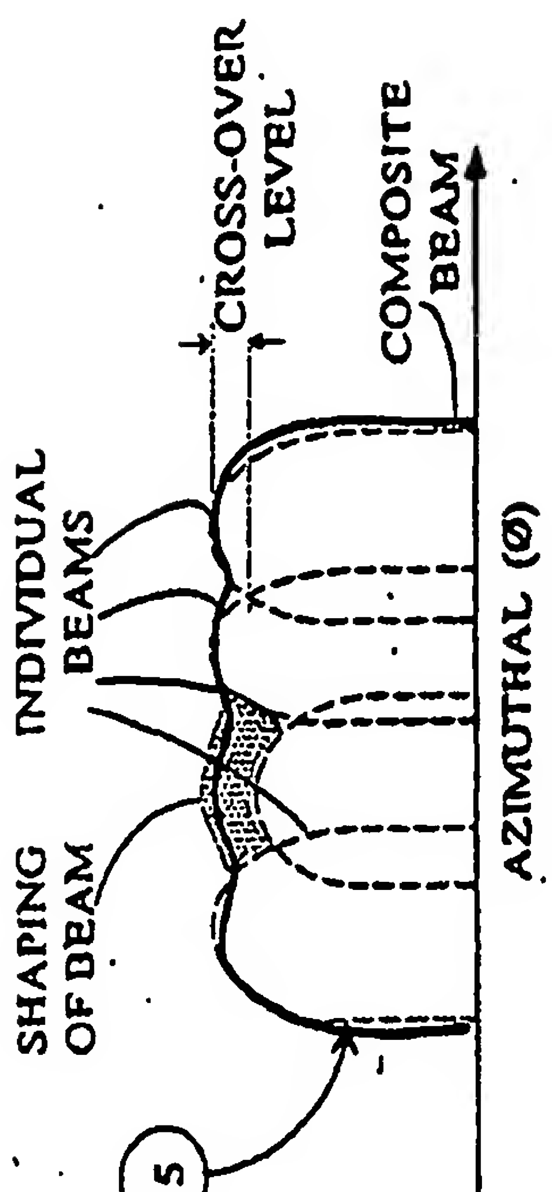

FIG. 2

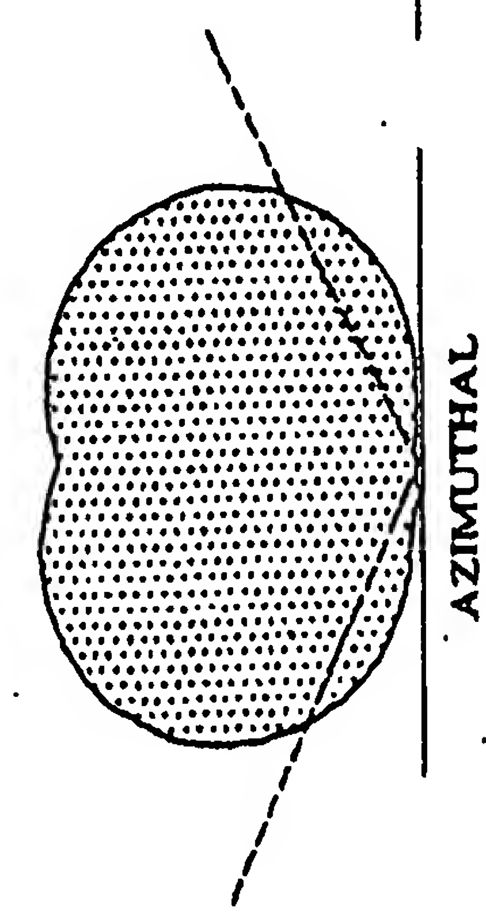

FIG. 3B

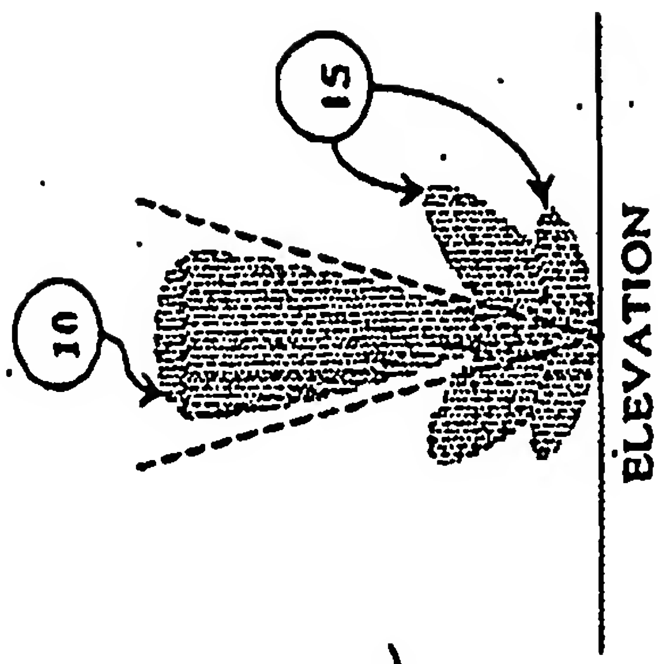

FIG. 3C

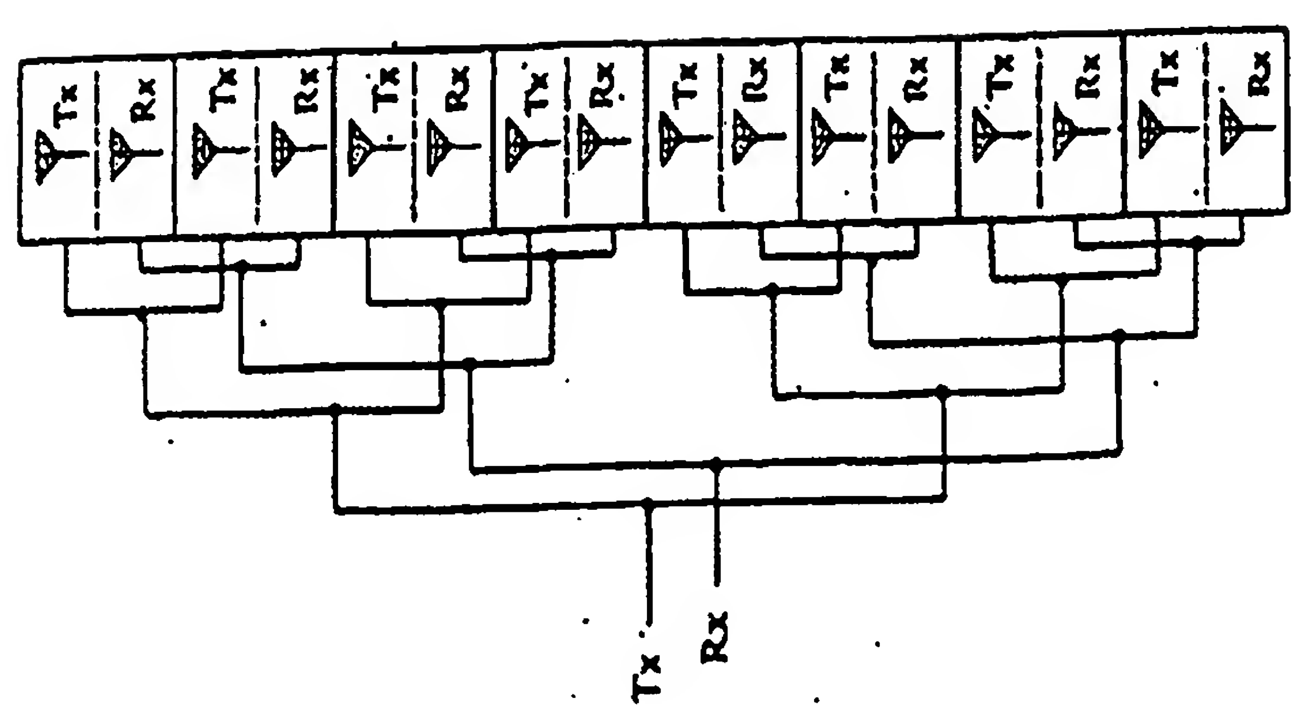

FIG. 3A

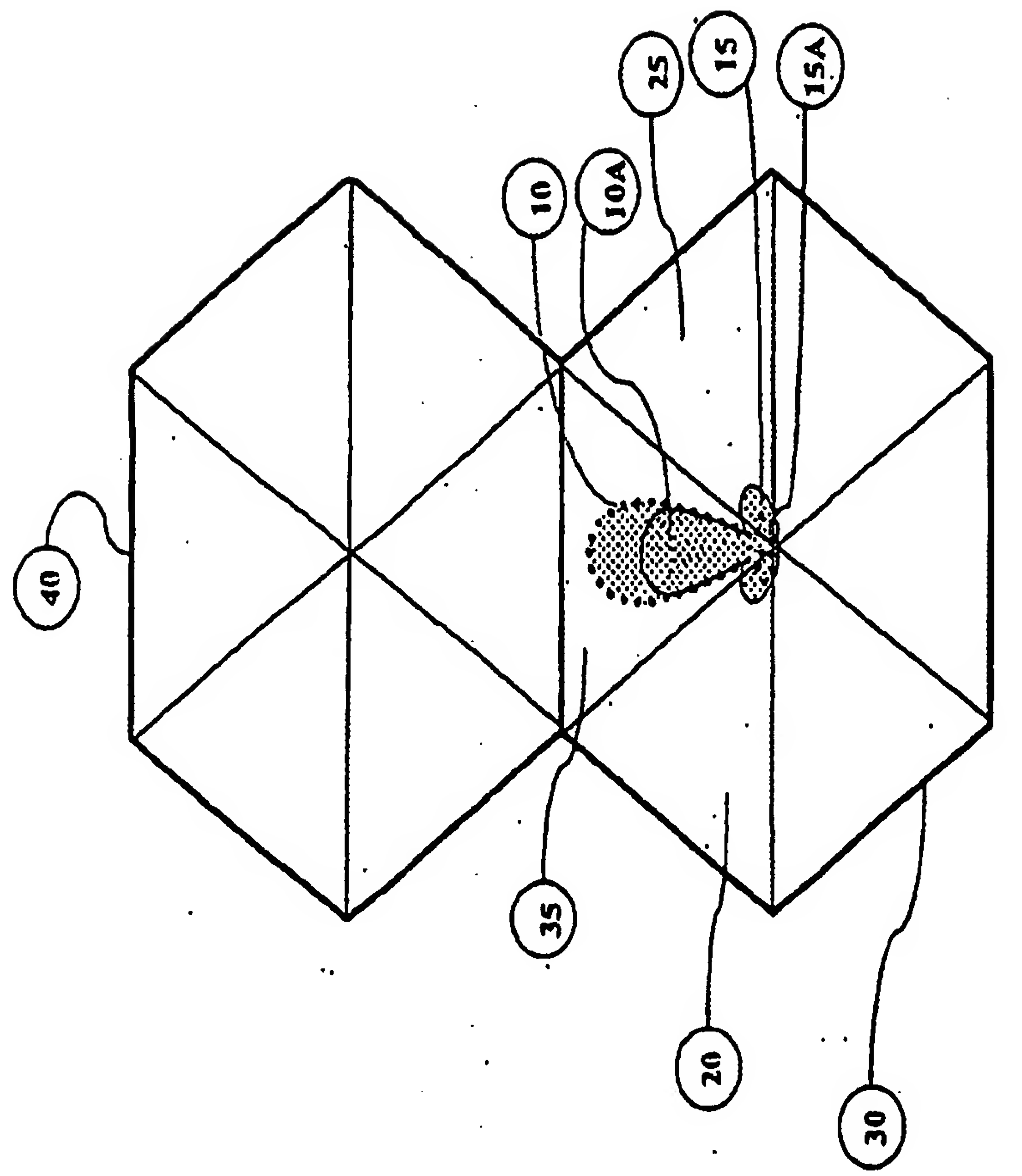

FIG. 4

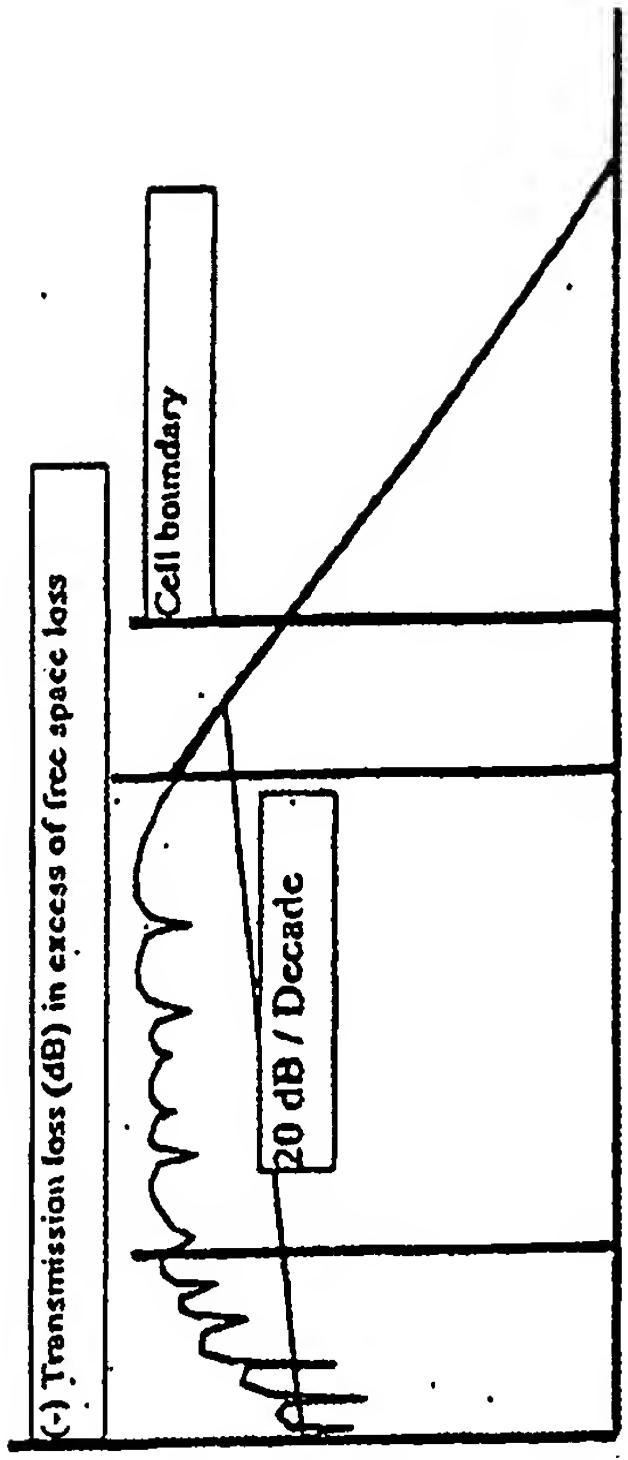
(-) Transmission loss (dB) in excess of free space loss
Cell boundary
20 dB / Decade

FIG. 5

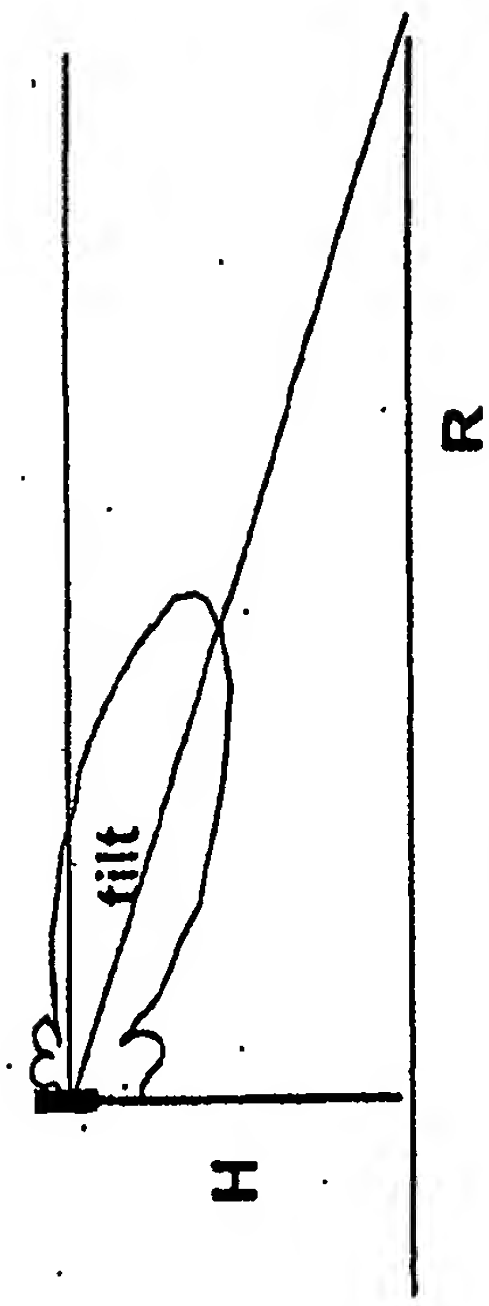
tilt
H
R

FIG. 6

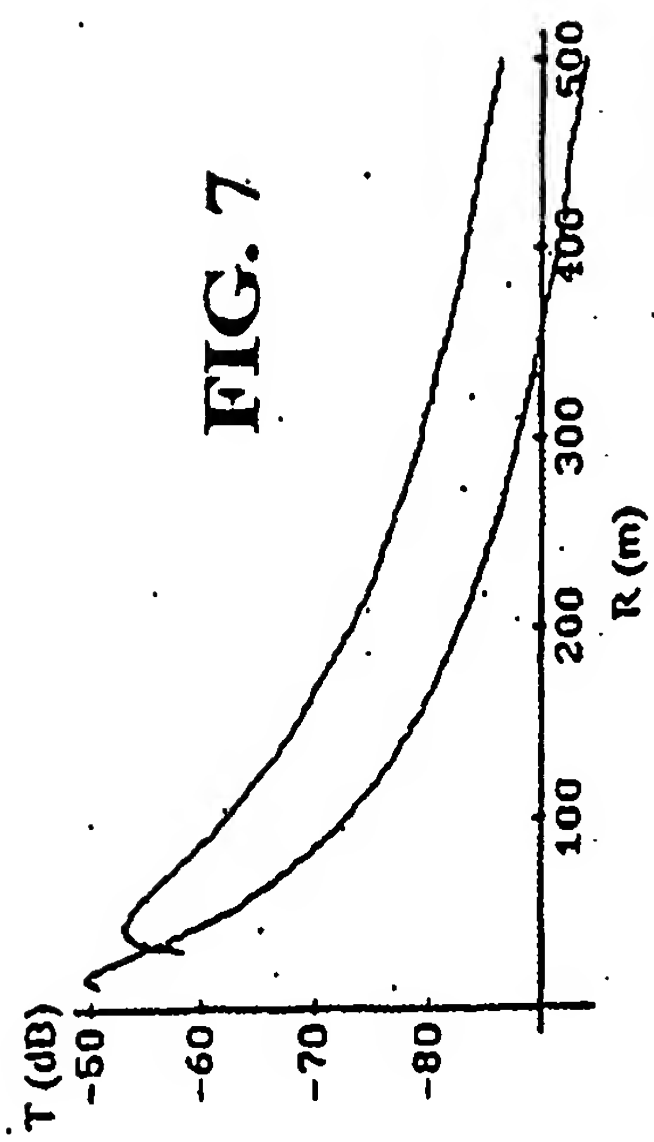
T (dB)
-50
-60
-70
-80
100
200
300
400
500
R (m)

FIG. 7

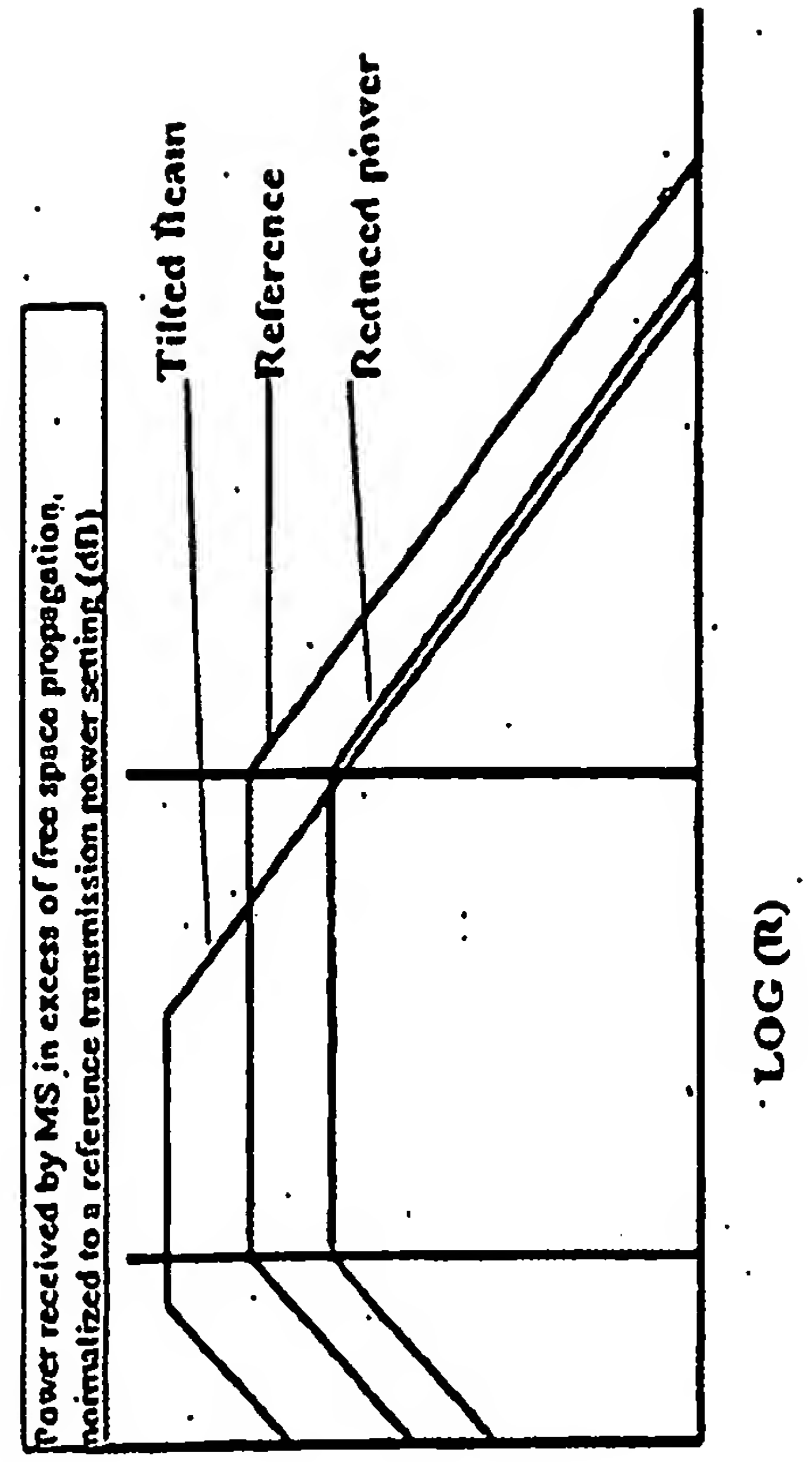
Power received by MS in excess of free space propagation, normalized to a reference transmission power setting (dB)
Tilted Beam
Reference
Reduced power
LOG (R)

FIG. 8

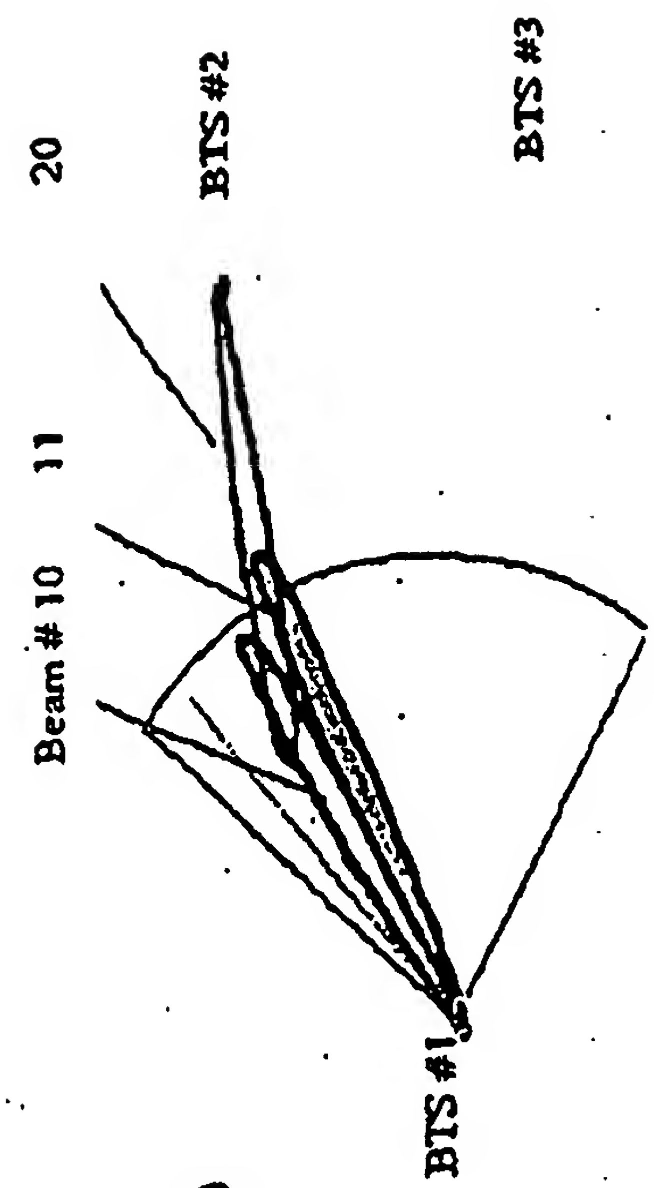
20
11
Beam # 10
BTS #2
BTS #3
BTS #1

FIG. 9

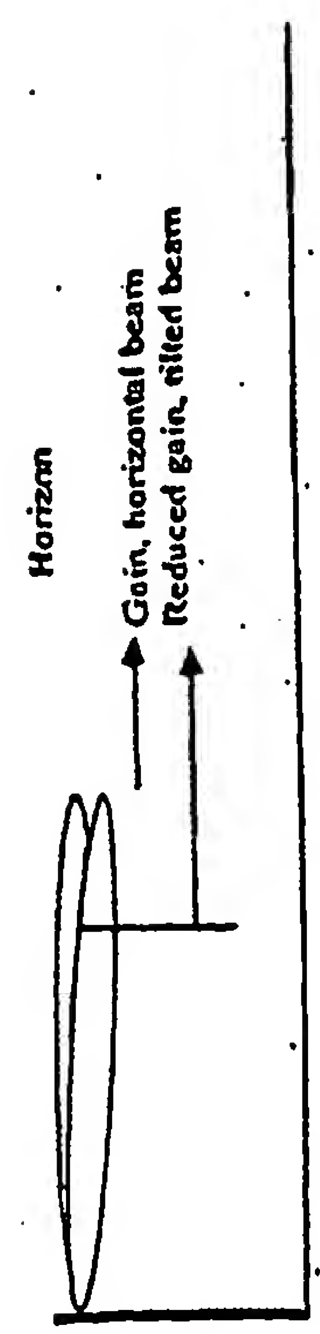
Horizon
Gain, horizontal beam
Reduced gain, tilted beam

FIG. 10

FIG. 11A